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RESEARCH MEMORANDUM

ADDITIONAL RESULTS IN A FREE-FLIGHT INVESTIGATION OF CONTROL EFFECTIVENESS OF FULL-SPAN, 0.2-CHORD PLAIN AILERONS AT HIGH SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS TO DETERMINE SOME EFFECTS OF WING SWEEPBACK, ASPECT RATIO, TAPER, AND SECTION THICKNESS RATIO

By

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

ADDITIONAL RESULTS IN A FREE-FLIGHT INVESTIGATION OF CONTROL EFFECTIVENESS OF FULL-SPAN, 0.2-CHORD PLAIN AILERONS AT HIGH SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS TO DETERMINE SOME EFFECTS OF WING SWEEPBACK, ASPECT RATIO, TAPER, AND SECTION THICKNESS RATIO

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SUMMARY

An aerodynamic-control-effectiveness investigation using free-flight, rocket-propelled test vehicles is being conducted by the Pilotless Aircraft Research Division of the Langley Memorial Aeronautical Laboratory. Additional results have been obtained recently which indicate some effects of wing sweepback, aspect ratio, taper ratio, and section thickness ratio on the rolling effectiveness of plain full-span, 0.2-chord, sealed ailerons.

The results of the present investigation are summarized in the following paragraphs.

For all configurations tested, the aileron rolling effectiveness at supersonic speeds was markedly lower than at subsonic speeds. The configurations having unswept wings experienced an abrupt loss of aileron rolling effectiveness in the Mach number range from about 0.85 to 1.00. Wing sweepback either reduced or eliminated this abrupt loss of aileron effectiveness.

The wing-aileron rolling effectiveness was considerably higher for the lower-aspect-ratio configurations than for the higher.

At zero sweep, tapering the wing reduced the loss of aileron rolling effectiveness in the Mach number range from 0.85 to 1.0 and increased slightly the supersonic rolling effectiveness. With 45° of sweepback, tapering the wing resulted in a small loss of control effectiveness in the Mach number range from 0.9 to 1.0 which was not obtained for the comparable untapered wing.

At zero sweep, reducing the section thickness ratio from 0.09 to 0.06 improved the aileron effectiveness characteristics in the

Mach number range from 0.85 to 1.0. With wing sweepback of 45°, a corresponding reduction in section thickness ratio did not materially affect the aileron effectiveness characteristics as a function of Mach number.

INTRODUCTION

At the present time there exists a need for experimental data relating to the design of aerodynamic controls for piloted and pilotless aircraft which are to be flown at transonic and supersonic speeds. Of the several experimental methods now available for obtaining this type of information, techniques utilizing rocket-propelled test vehicles in free flight afford the possibility of obtaining some of the desired measurements continuously over the Mach number range from subsonic to supersonic at relatively large scale. As a result, the Pilotless Aircraft Research Division of the Langley Memorial Aeronautical Laboratory is engaged in an investigation the purpose of which is to provide experimental information relating to aerodynamic control effectiveness at high subsonic, transonic, and supersonic speeds using rocket-propelled free-flight test vehicles. The exploratory phase of this program is being conducted with the RM-5 test vehicle with which data relating to the rolling capabilities of wing-aileron combinations are obtained.

The RM-5 is a relatively simple test vehicle consisting of a pointed, cylindrical body at the rear of which are attached wings having pre-set, fixed, aileron-type controls. In flight the rolling velocity produced by the ailerons is measured by means of special radio equipment. The flight-path velocity is measured with Doppler radar. These measurements, in conjunction with atmospheric data obtained with radiosondes, permit the evaluation of the wing-aileron rolling effectiveness as a function of Mach number. The measurements obtained permit the direct evaluation only of the rolling capabilities of wing-aileron combinations; however, it is possible to obtain general qualitative information with regard to aerodynamic control effectiveness. A complete description of the RM-5 testing technique is given in references 1 and 2.

In addition to the description of the RM-5 testing technique, references 1 and 2 contain data obtained in previous RM-5 launchings which indicate some effects of wing sweepback, taper, aspect ratio, and section thickness ratio on the rolling effectiveness of plain, sealed, full-span, 0.2-chord ailerons. The purpose of the present report is to present data obtained in recent RM-5 launchings which indicate some additional effects of wing sweepback, taper, aspect ratio, and section thickness ratio on the rolling effectiveness of the aforementioned wing-aileron configuration. All of the control-effectiveness data presented in references 1 and 2 are included in the present report.

SYMBOLS

$\frac{pb}{2V}$ wing-tip helix angle, radians

p rolling velocity, radians per second

b diameter of circle swept by wing tips, feet (with regard to rolling characteristics, this is considered to be the effective span of the three-fin RM-5 models)

V flight-path velocity, feet per second

C_D drag coefficient based on total exposed wing area of 1.563 sq ft

M Mach number

Λ sweepback of 50-percent-chord line of wing

$\Lambda_{L.E.}$ sweepback of leading edge of wing

$\Lambda_{T.E.}$ sweepback of trailing edge of wing

b_1 diameter of circle swept by wing tips minus fuselage diameter

S_1 exposed area of two wing panels

A exposed aspect ratio $\left(b_1{}^2/S_1\right)$

λ wing taper ratio $\left(c_t/c_r\right)$

c_r wing chord at side of fuselage

c_t wing-tip chord

δ_a aileron deflection measured in plane perpendicular to chord plane and parallel to model center line

APPARATUS AND TESTS

Test Vehicles

The general arrangement of the RM-5 test vehicles used in the present investigation is shown in the drawing of figure 1 and the photographs of figure 2. The models are constructed mainly of wood for ease of construction and lightness. The body is of balsa except at the wing attachment where spruce is used. The wings are constructed of laminated spruce with steel stiffeners cyclewelded into the upper and lower wing surfaces to provide the required torsional rigidity. (See fig. 1.) The degree of wing torsional rigidity required to minimize the adverse effects of wing twisting on the rolling power of the ailerons has been determined by flight tests of two RM-5 configurations which were identical except for the degree of wing torsional rigidity. These tests, which are reported in reference 2, indicated that the loss of aileron power due to wing twisting has been reduced to the extent that the main aerodynamic effects are not obscured.

The configurations for which results are presented in this report are given in the table in figure 1. In all tests, the body shape, the exposed wing area (225 sq in.) and the control (0.2c, full-span, plain, sealed aileron) were constant. It was intended that the aileron deflections for all the configurations reported herein would be 5°, however, because of difficulties in construction and because the ailerons were not adjustable, the actual deflections varied from 3.0° to 6.0°. The airfoil sections and the control deflections were always measured in the free-stream direction. The aileron, which was formed by deflecting the section chord line at the 0.8c point, simulates a sealed, faired, plain aileron in actual airplane or missile construction.

The test vehicles are propelled by standard 3.25-inch aircraft rocket motors which are contained within the fuselage. The rocket motor develops a thrust of 2000 pounds for about 1 second. Some of the test vehicles used in recent launchings were boosted by means of the booster arrangement shown in figure 3. A photograph of a test vehicle with its booster on the launching ramp is shown in figure 4. The unboosted test vehicles attain a Mach number of about 1.3; the boosted test vehicles attain a Mach number of about 1.7.

Test Method

The actual launching of the test vehicles is accomplished at the Wallops Island test facility of the Pilotless Aircraft Research Division of the Langley Memorial Aeronautical Laboratory. The test vehicles are launched from a rail-type launcher at an elevation angle of about 75°. The test measurements are obtained during a 12-second period following rocket-motor burnout during which period the flight path is essentially straight as shown by the calculated flight paths of figure 5. In flight, the rolling velocity produced by the ailerons and the flight-path velocity of the test vehicle are obtained as time histories. The rolling-velocity data are obtained by means of a special radio transmitter (spinsonde) in the nose of the model. The flight-path velocity is obtained by means of continuous-wave Doppler radar. These data, in conjunction with atmospheric data obtained with radiosondes at the time of launching, permit the evaluation of the rolling effectiveness of the particular wing-aileron configuration under investigation in terms of the parameters $\frac{pb}{2V}$ or $\frac{pb/2V}{\delta_a}$ as a function of Mach number. In addition, the variation of drag coefficient with Mach number for the test vehicle is obtained by a method involving the differentiation of the curve of flight-path velocity against time for power-off flight. The relatively large scale of the tests is indicated by the curves of Reynolds number against Mach number shown in figure 6. The Reynolds number is based on the average exposed chord parallel to model center line.

Accuracy

Determination of $\frac{pb/2V}{\delta_a}$.- The following factors are considered in estimating the accuracy of the determination of $\frac{pb/2V}{\delta_a}$: the accuracy of model construction, the limitations on the instrumentation, and the effects of finite rolling moment of inertia.

The accuracy of model construction as indicated by results obtained with supposedly identical models is such as to result in one case, models 53a and 53b, in variations in $\frac{pb/2V}{\delta_a}$ as large as 0.002. However, in the majority of cases for which results for identical models are available, the variations in $\frac{pb/2V}{\delta_a}$ due to discrepancies in the models are considerably smaller.

The accuracy of the measurement of the rolling velocity p and the flight-path velocity V is estimated to be within the following limits:

p, ±1.5 radians per second

V, ±5.0 feet per second

Using the above values, the maximum error in the quantity $\frac{pb/2V}{\delta_a}$ due to instrumentation is estimated to be within ±0.0005.

It should be noted, as pointed out in reference 1, that owing to the relatively small rolling moment of inertia the values of $\frac{pb}{2V}$ obtained during flight are substantially steady-state values even though the model is experiencing an almost continual rolling acceleration or deceleration. Except for abrupt changes in $\frac{pb}{2V}$ such as occur for model 50a in the Mach number range from 0.85 to 1.00, the correction for steady-state conditions is less than ± 3 percent. The plus sign applies if the test vehicle is experiencing a rolling acceleration and the minus sign applies if the test vehicle is experiencing a rolling deceleration at any instant. For abrupt changes in $\frac{pb}{2V}$ such as occur in the Mach number range from 0.85 to 1.00 for model 50a the correction is estimated to be ± 20 percent. Inasmuch as the correction to steady-state conditions involves an estimation of the damping in roll which cannot now be determined with sufficient accuracy at transonic speeds, no correction has been applied to the measured values of $\frac{pb}{2V}$.

Determination of C_D.- The drag coefficient is calculated by a process involving the graphical differentiation of the curve of flight-path velocity against time obtained with continuous-wave Doppler radar. The resulting longitudinal decelerations during the period after rocket-motor burnout can be more accurately determined for the large values of decelerations and drag which occur at supersonic speeds than for the smaller decelerations and drag forces encountered at subsonic speeds. The error in drag coefficient is therefore smaller at supersonic speeds than at subsonic speeds. The accuracy of the drag coefficient is estimated to be within the following limits: supersonic speeds, ± 0.002; subsonic speeds, ± 0.003.

Determination of Mach number.- The accuracy of the Mach number determination is within ± 0.01.

RESULTS AND DISCUSSION

The results of recent RM-5 test vehicle launchings are presented in figure 7 as curves of $\frac{pb}{2V}$ and drag coefficient against Mach number. These results are combined with results presented in references 1 and 2 in figures 8 through 11 as curves of $\frac{pb/2V}{\delta_a}$ and drag coefficient against Mach number. It should be noted that the quantity $\frac{pb/2V}{\delta_a}$ is simply the ratio of $\frac{pb}{2V}$ to δ_a for a particular δ_a; it is not to be considered as the uniform rate of change of $\frac{pb}{2V}$ with δ_a inasmuch as the variation of $\frac{pb}{2V}$ with δ_a may not be linear over certain Mach number ranges.

Aileron Control Characteristics

Effect of sweepback.– The effect of sweepback on the rolling effectiveness of plain, 0.2-chord, full-span ailerons is shown in figures 8(a) and 8(b) for aspect ratios of 1.75 and 3.00, respectively. For both aspect ratios, wing sweepback of 30° reduced the abrupt loss of aileron effectiveness characteristics of the unswept wings in the Mach number range from approximately 0.85 to 1.00. Inasmuch as the radar flight-path velocity measurements were not obtained, the flight-path velocity for configuration 78(b), figure 8(b), was calculated from known characteristics of the rocket motor and the test vehicle. It is believed that the estimated flight-path velocity is lower than the actual velocity and as a result the curve of $\frac{pb/2V}{\delta_a}$ appears to be shifted in the direction of lower Mach number. It should also be noted that the measured values of $\frac{pb/2V}{\delta_a}$ for configuration 79(b) are considerably lower than would be expected on the basis of subsonic experience regarding the effects of sweepback on aileron effectiveness. This discrepancy in the results is attributed to inaccuracies in construction which were not detected in the pre-flight inspection which is made of each model tested. Unfortunately the method of testing precludes the possibility of examining the models after the test results have been obtained. For aspect ratio 3.0 and sweepback of 45°, the change in aileron effectiveness over the Mach number range investigated was gradual and without any abrupt change. With aspect ratio 1.75 and sweepback of 45°, a small change of effectiveness was measured in the Mach number range from 0.94 to 0.98. At supersonic speeds the sweptback configurations generally retained a larger part of their subsonic rolling effectiveness than did the unswept configurations. Increasing the Mach number from 1.0 to the maximum attained in the tests, resulted in a gradual reduction of aileron effectiveness with no abrupt changes for all configurations tested.

It is interesting to note that sweepback does not simply delay to a higher Mach number the abrupt changes in aileron characteristics obtained for the unswept wings in the Mach number range from 0.85 to 1.00, but rather that sweep reduces or eliminates these adverse aileron characteristics which, when they occur, are limited to the Mach number range from about 0.85 to 1.00.

Effect of aspect ratio.– Some effects of aspect ratio on the rolling power of the wing-aileron configurations being investigated are shown in figures 9(a), 9(b), and 9(c). These data show that at supersonic Mach numbers the aspect ratio 1.75 configurations exhibit considerably higher rolling-effectiveness characteristics than do the aspect ratio 3.0 configurations. In the vicinity of Mach number 1, the lower-aspect-ratio configurations develop a larger part of their subsonic rolling effectiveness than do the higher-aspect-ratio configurations. For aspect ratio of 1.75 and sweepback of 45° the rolling effectiveness in the vicinity of Mach number of 0.97 actually increases slightly with Mach number while the corresponding configuration of aspect ratio 3.0 exhibits a smooth variation of $\frac{pb/2V}{\delta_a}$ over the same Mach number range.

Effect of taper.— The effect of wing taper on the aileron characteristics is shown in figures 10(a) and 10(b) for sweepback angles of 0° and 45°. With zero sweep tapering the wing reduced the loss of aileron control effectiveness in the Mach number range from 0.85 to 1.00 and increased slightly the supersonic rolling effectiveness. With 45° sweepback, tapering the wing resulted in a small loss of control effectiveness in the Mach number range from 0.9 to 1.0 which was not obtained for the comparable untapered wing.

Effect of section thickness ratio.— The effect of section thickness ratio on the rolling characteristics of the wing-aileron configurations being tested is shown in figures 11(a) and 11(b) for sweep angles of 0° and 45°. At zero sweep reducing the section thickness ratio from 0.09 to 0.06 decreased the severity of the loss of aileron effectiveness at transonic speeds and increased somewhat the Mach number at which the aileron experienced a loss of effectiveness. With 45° of sweepback the 0.06- and 0.09-thickness-ratio configurations have generally the same rolling characteristics except at the highest Mach numbers where the reduced effectiveness of 0.06-thickness-ratio configuration is attributed to greater wing twisting. Rough calculations have indicated that the 45° swept wing of 0.06 section thickness ratio is the only configuration for which the wing torsional stiffness was not sufficient to reduce to a negligible amount the effects of wing twisting on aileron rolling effectiveness. With 45° of sweepback, the 0.12-thickness-ratio configuration exhibited a small loss of aileron effectiveness in the Mach number range from about 0.89 to 0.96 and a lower rolling effectiveness at supersonic speeds than the 0.06- and 0.09-thickness-ratio configurations. The aforementioned loss of aileron effectiveness for the 0.12-thickness-ratio configuration is partly attributed to the aileron deflection which was only 3.5°; the aileron effectiveness is probably not linear with deflection in this Mach number range.

Drag Measurements

The drag-coefficient data obtained in the present investigation are included as a matter of interest and to illustrate the relation between transonic drag rise and control effectiveness. In examining these data, consideration should be made of the section angle-of-attack distribution along the wing span caused by model rotation. The trends of the results, however, are in agreement with the results of the free-flight rocket-propelled drag investigation described in reference 3.

It is interesting to note that the configurations which exhibited abrupt changes in control effectiveness at transonic speeds also exhibited the largest drag increases at transonic speeds.

There appears to be a consistent discrepancy between the drag values measured for the boosted and unboosted models. For example, in figure 7(a) the drag of a boosted model, 59b, is lower than that for the equivalent unboosted model, 59a. This discrepancy may be a result of differences in the shape of the model at the extreme rear when the booster fittings are installed. (See figs. 1 and 3.) A new booster system which has been devised for use in future tests will not alter the rear end of the model and will probably eliminate these discrepancies.

CONCLUSIONS

The following conclusions regarding the aerodynamic control effectiveness of plain, sealed, 0.2-chord, full-span ailerons are indicated by the free-flight tests of wing-body combinations reported herein:

1. For all configurations tested, the aileron rolling effectiveness at supersonic speeds was markedly lower than at subsonic speeds.

2. The configurations having unswept wings experienced an abrupt loss of aileron rolling effectiveness in the Mach number range from about 0.85 to 1.00. Wing sweepback either reduced or eliminated this abrupt loss of aileron effectiveness.

3. The wing-aileron rolling effectiveness was considerably higher for the lower-aspect-ratio configurations than for the higher.

4. At zero sweep, tapering the wing reduced the loss of aileron rolling effectiveness in the Mach number range from 0.85 to 1.0 and increased slightly the supersonic rolling effectiveness. With 45° of sweepback, tapering the wing resulted in a small loss of control effectiveness in the Mach number range from 0.9 to 1.0 which was not obtained for the comparable untapered wing.

5. At zero sweep, reducing the section thickness ratio from 0.09 to 0.06 improved the aileron effectiveness characteristics in the Mach number range from 0.85 to 1.0. With wing sweepback of 45°, a corresponding reduction in section thickness ratio did not materially

affect the aileron effectiveness characteristics as a function of Mach number; however, wing twisting effects become apparent above a Mach number of 1.15 for the 0.06-thickness-ratio configuration.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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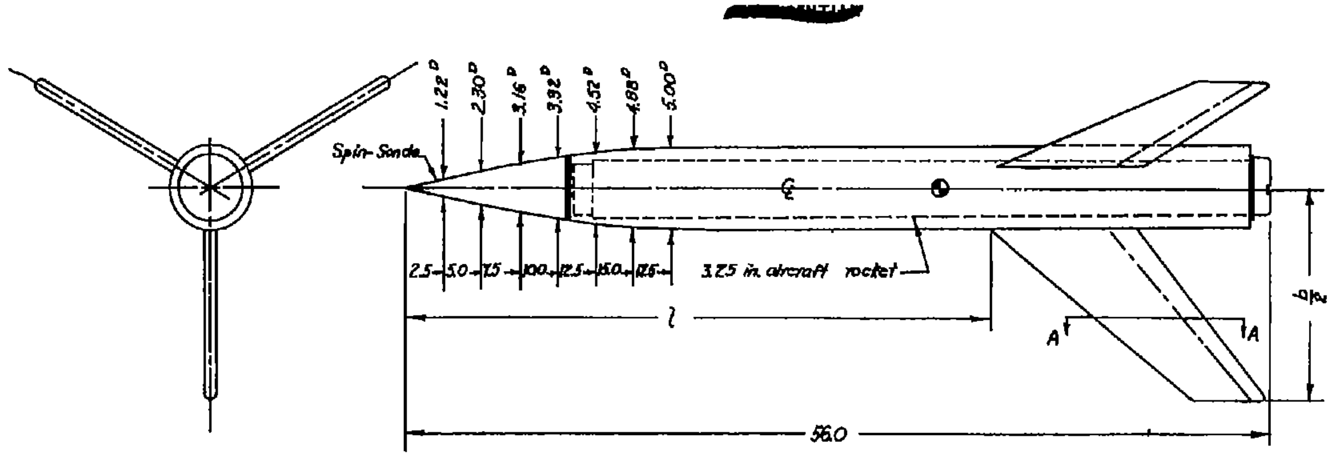
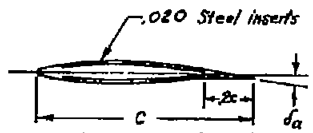
1. Sandahl, Carl A., and Marino, Alfred A.: Free-Flight Investigation of Control Effectiveness of Full-Span 0.2-Chord Plain Ailerons at High Subsonic, Transonic, and Supersonic Speeds to Determine Some Effects of Section Thickness and Wing Sweepback. NACA RM No. L7D02, 1947.

2. Sandahl, Carl A.: Free-Flight Investigation of Control Effectiveness of Full-Span, 0.2-Chord Plain Ailerons at High Subsonic, Transonic, and Supersonic Speeds to Determine Some Effects of Wing Sweepback, Taper, Aspect Ratio, and Section Thickness Ratio. NACA RM No. L7F30, 1947.

3. Tucker, Warren A., and Nelson, Robert L.: Drag Characteristics of Rectangular and Swept-Back NACA 65-009 Airfoils Having Various Aspect Ratios as Determined by Flight Tests at Supersonic Speeds. NACA RM No. L7C05, 1947.

[redacted]

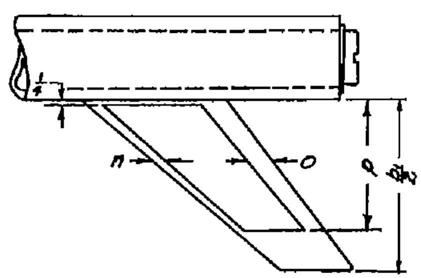




Section @ A-A (typical)

Center of gravity is at station 35 (approx)

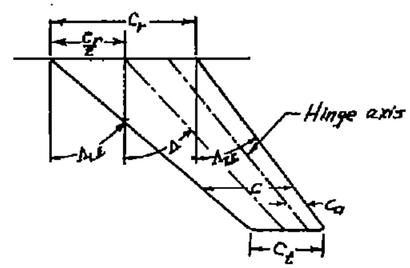
All dimensions are in inches



Inserts details

Model no.	Aspect ratio, A	Sweepback, Λ, deg	Λ_{LE}	Λ_{TE}	Taper ratio, λ	NACA airfoil section	Aileron deflection, δ_a, deg. (a)	Source	$\frac{b}{2}$ in.	c_r in.	c_t in.	l in.	$\frac{c_a}{c}$	$\frac{a}{c}$	$\frac{a}{c}$	$\frac{p}{q_e}$
50a	3.0	0	0	0	1.0	65-009	4.4	Ref. 1	13.11	7.07	7.07	47.0	0.20	0.10	0.10	0.35
50b	3.0	0	0	0	1.0	do	4.0	do	do	do	do	do				
51a	3.0	0	0	0	1.0	65-006	5.1	do	do	do	do	do				
52c	3.0	0	12.5	-12.5	0.5	65-009	5.0	Pres. tests	do	9.43	4.71	45.4				
53a	3.0	45	45	45	1.0	do	5.6	Ref. 1	do	7.07	7.07	39.0				
53b	3.0	45	45	45	1.0	do	4.9	do	do	do	do	do				
54a	3.0	45	45	45	1.0	65-006	5.0	Ref. 2	do	do	do	do			0.25	
55a	3.0	45	51	38	.5	65-009	6.0	do	do	9.43	4.71	37.7			0.20	
57a	1.75	0	0	0	1.0	do	5.0	do	10.60	9.26	9.26	45.4				
57b	1.75	0	0	0	1.0	do	5.0	do	do	do	do	do				
59a	1.75	45	45	45	1.0	do	3.0	Pres. tests	do	do	do	39.5				
59b	1.75	45	45	45	1.0	do	3.2	do	do	do	do	do				
78b	3.0	30	30	30	1.0	do	4.3	do	13.11	7.07	7.07	41.5				
79b	1.75	30	30	30	1.0	do	4.3	do	10.60	9.26	9.26	42.0				
80a	3.0	45	45	45	1.0	65-012	3.5	do	13.11	7.07	7.07	39.0				

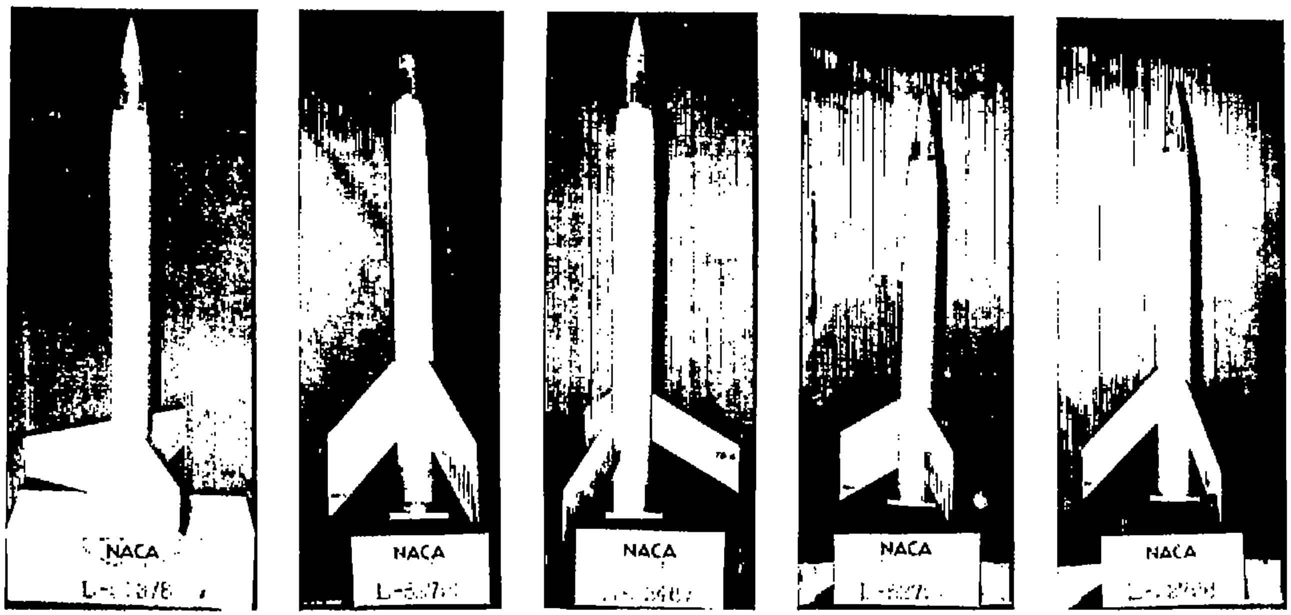
(a) Average aileron deflection for three fins.



Planform details

[redacted]

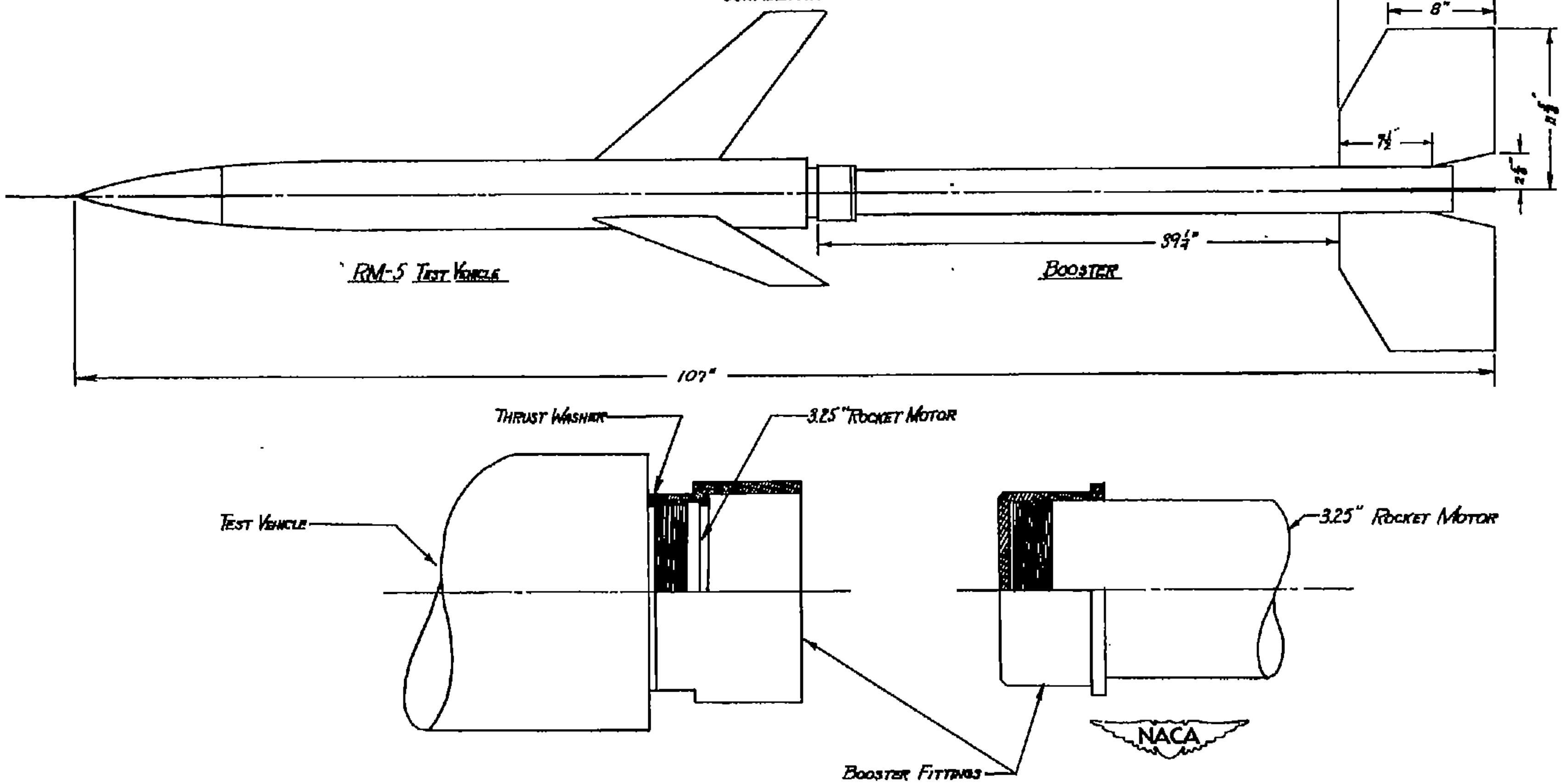
Figure 1.- General arrangement of RM-5 Models.



(a) 52. (b) 59. (c) 78. (d) 79. (e) 80.

Figure 2.- Model configurations of present tests.

[redacted]



[redacted]

Figure 3.- Method of booster attachment.

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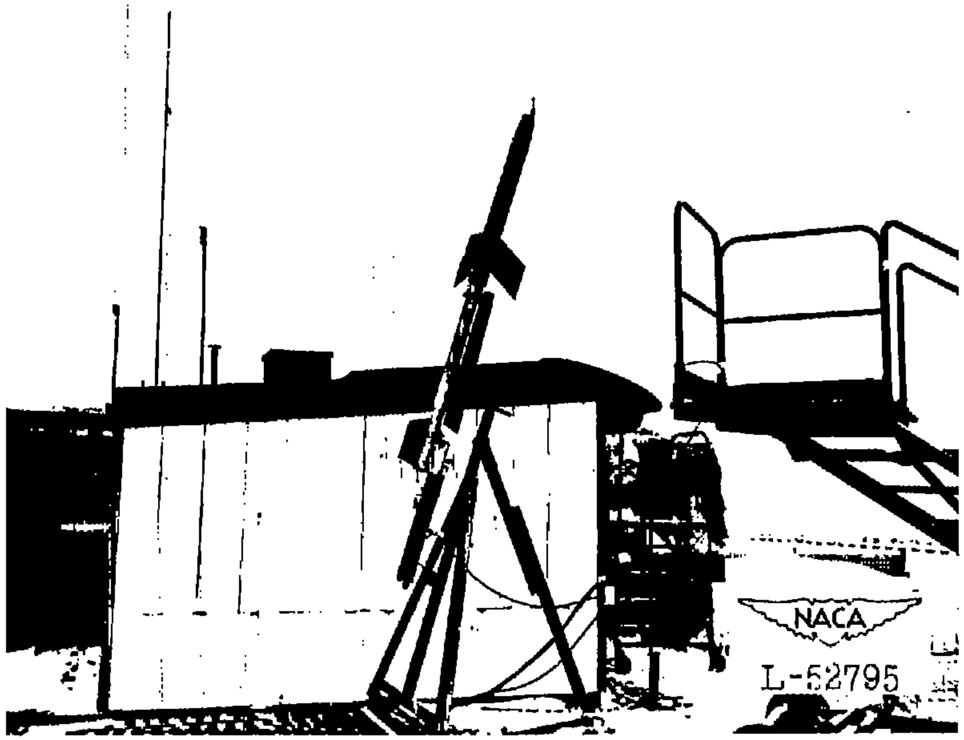

Figure 4.- Method of launching boosted models.

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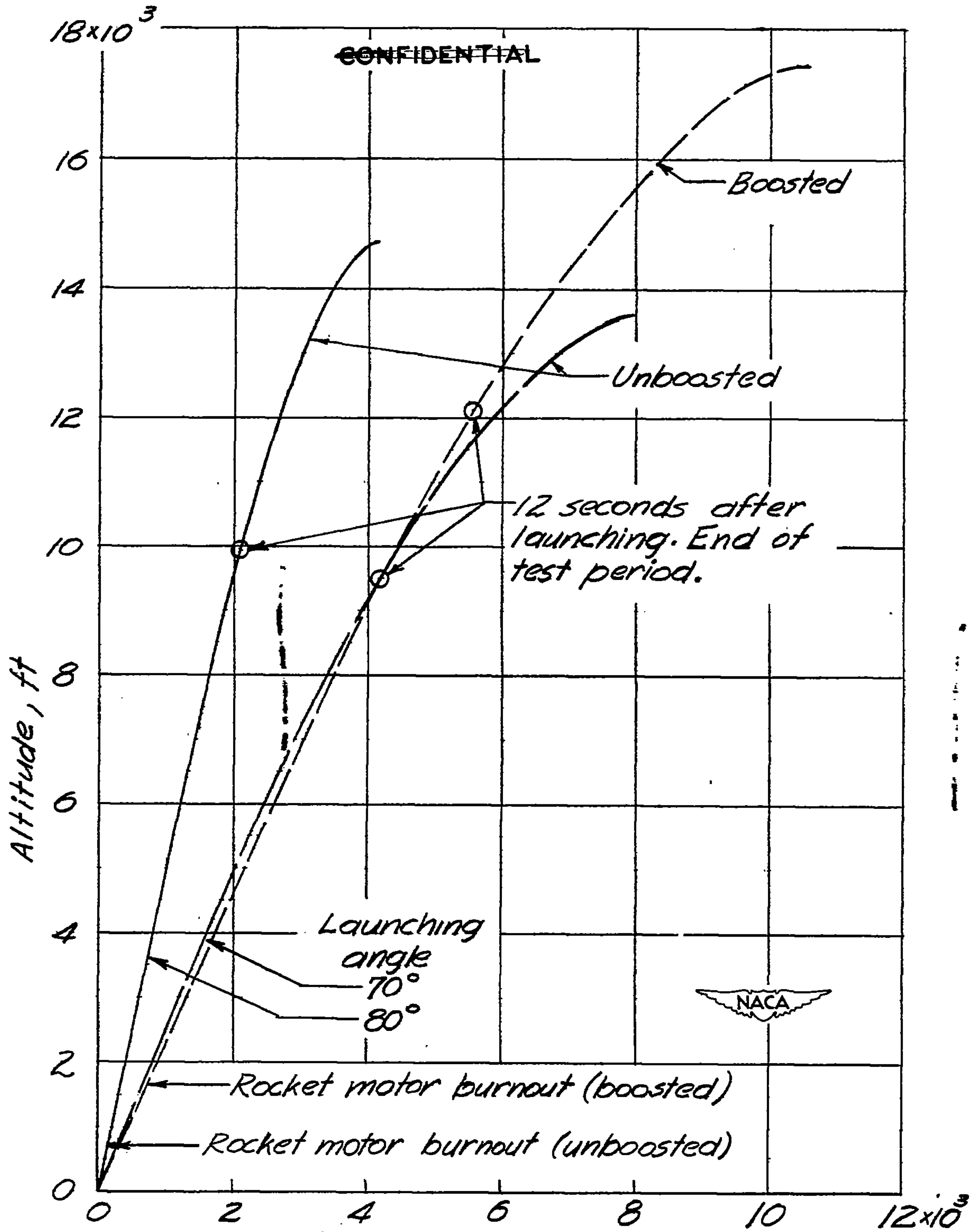

Figure 5.- Calculated flight paths of RM-5 test vehicles.

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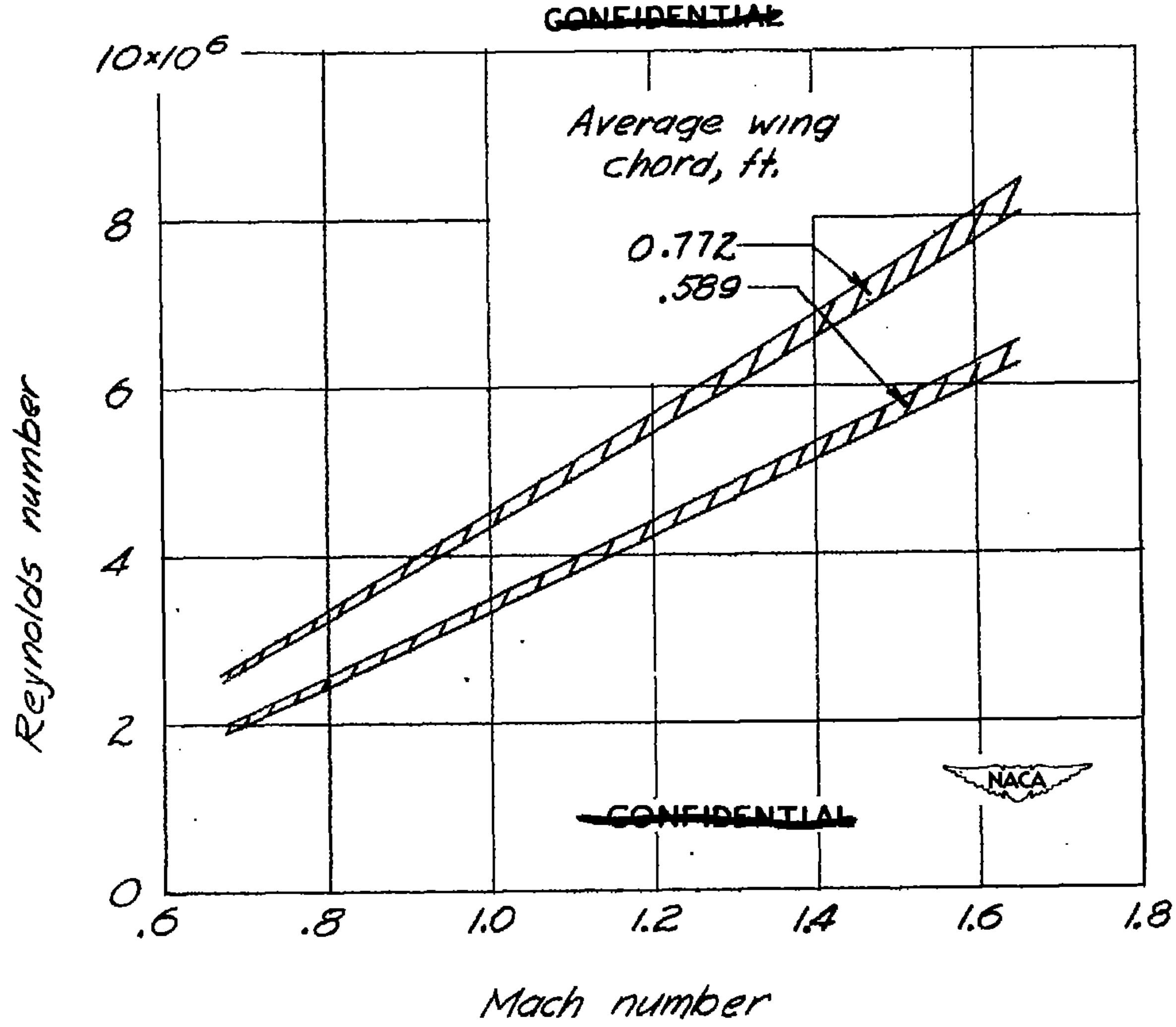
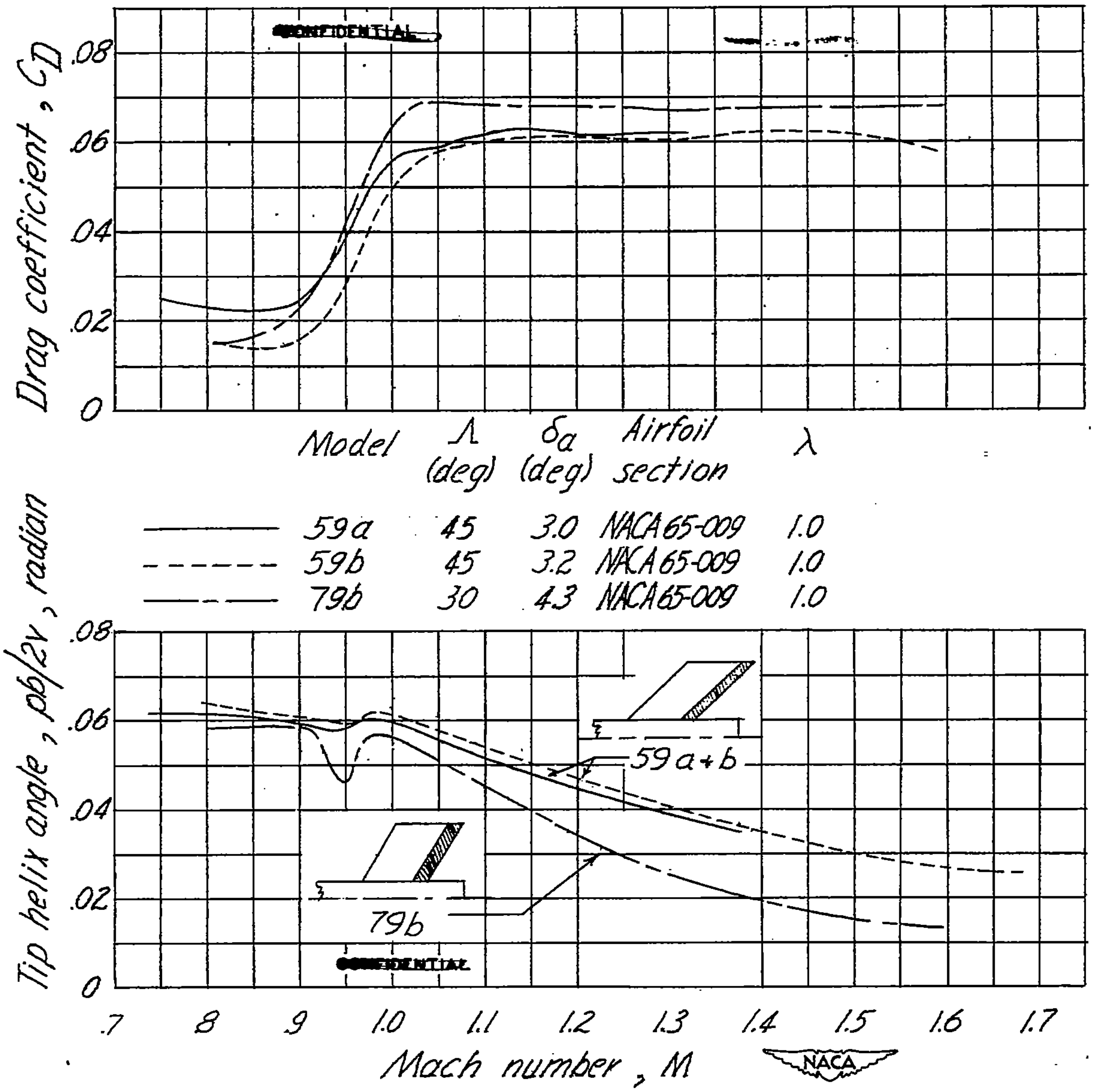
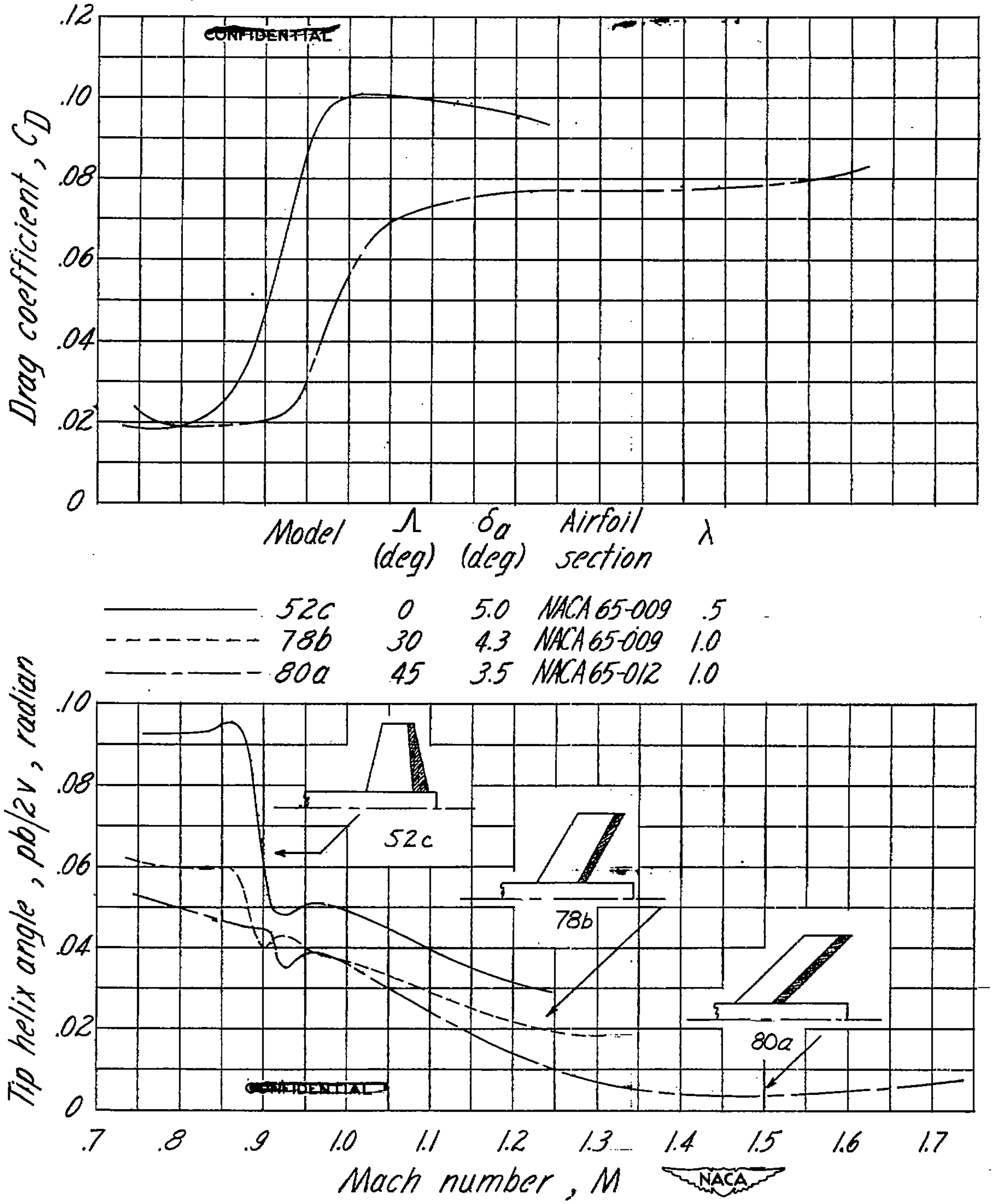


Figure 6.-Variation of Reynolds number with Mach number for the range of climatic conditions encountered during tests.



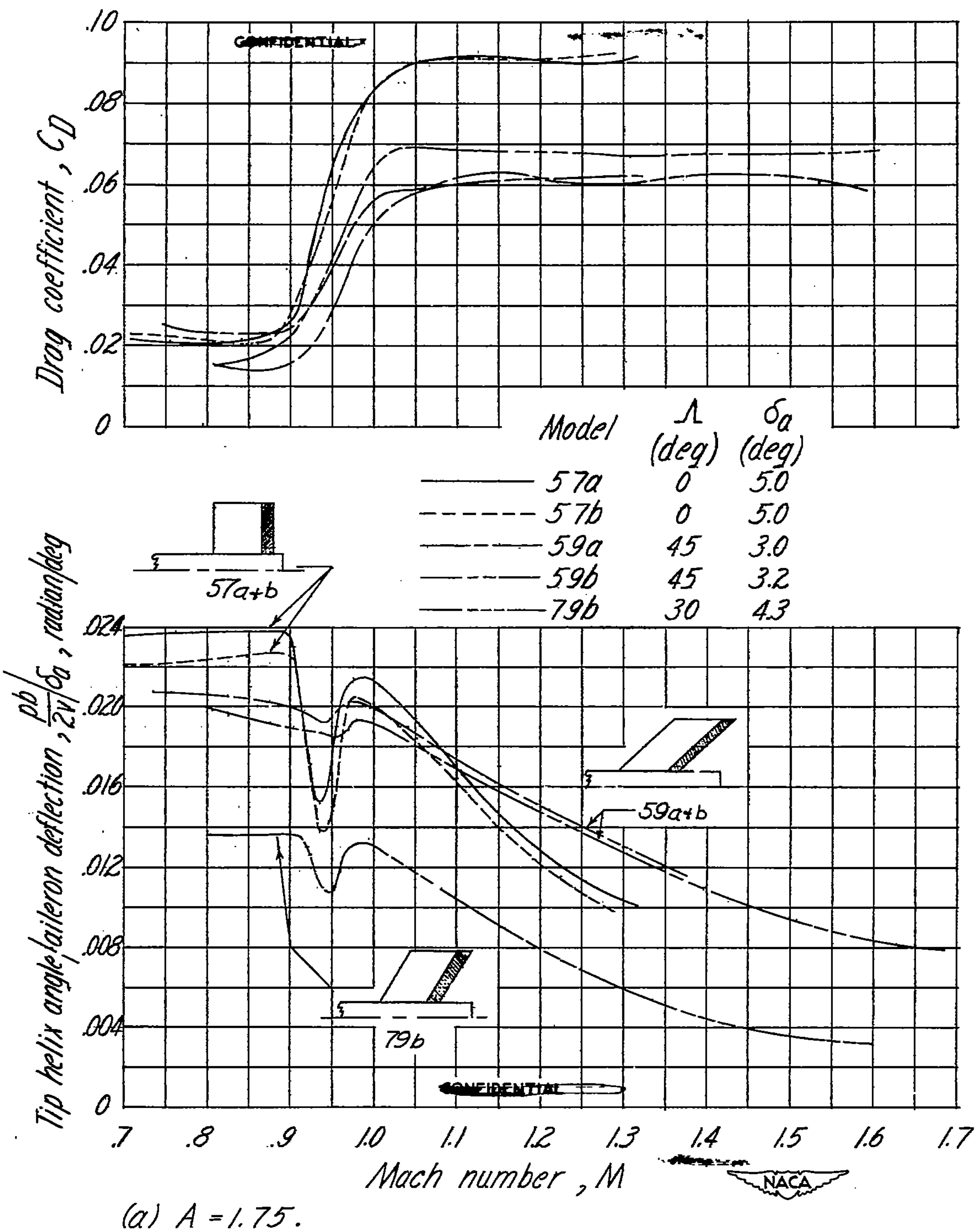
(a) A = 1.75.

Figure 7.- Results obtained during recent launchings of RM-5 test vehicles. [redacted]



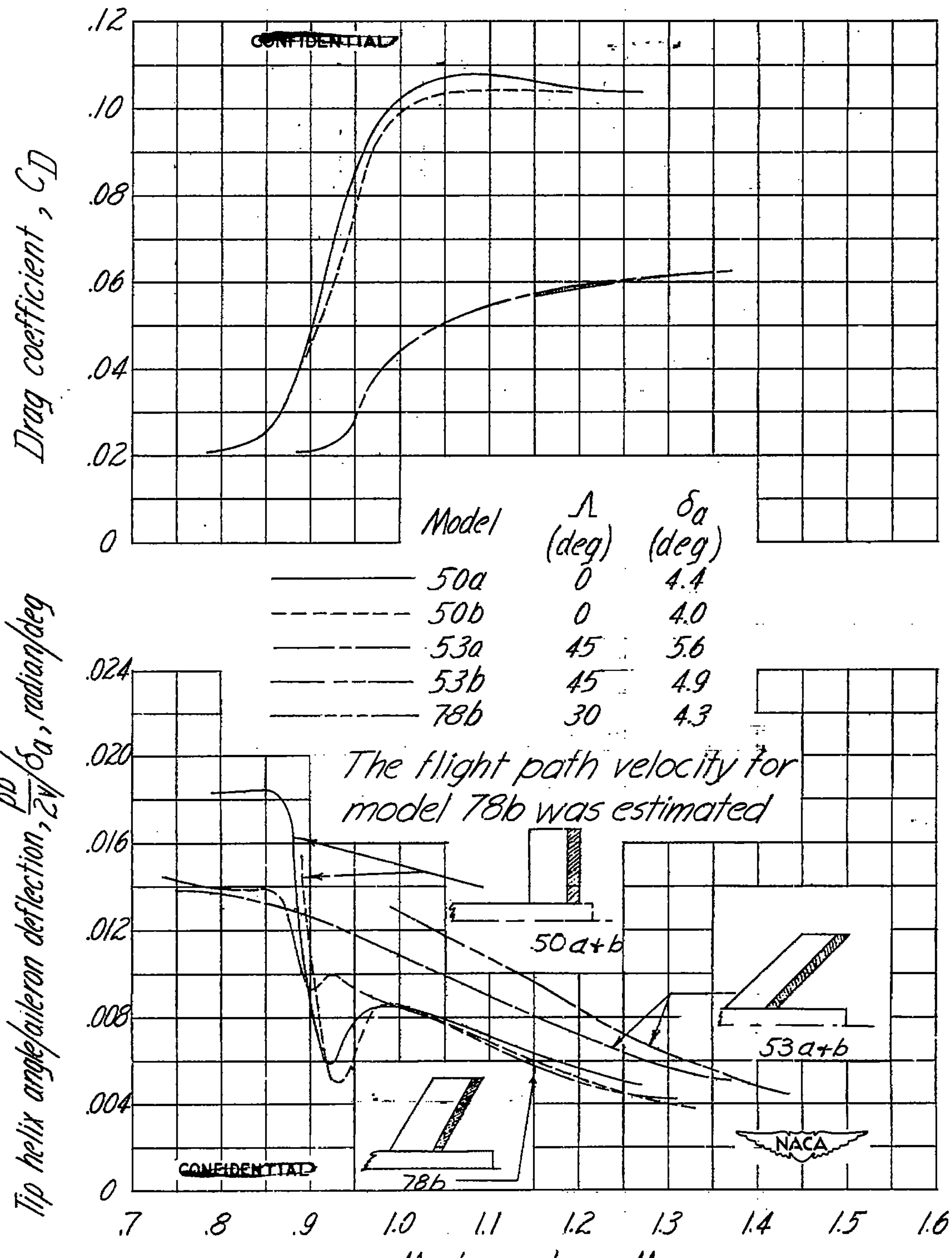
(b) A = 3.0.

Figure 7.- Concluded.



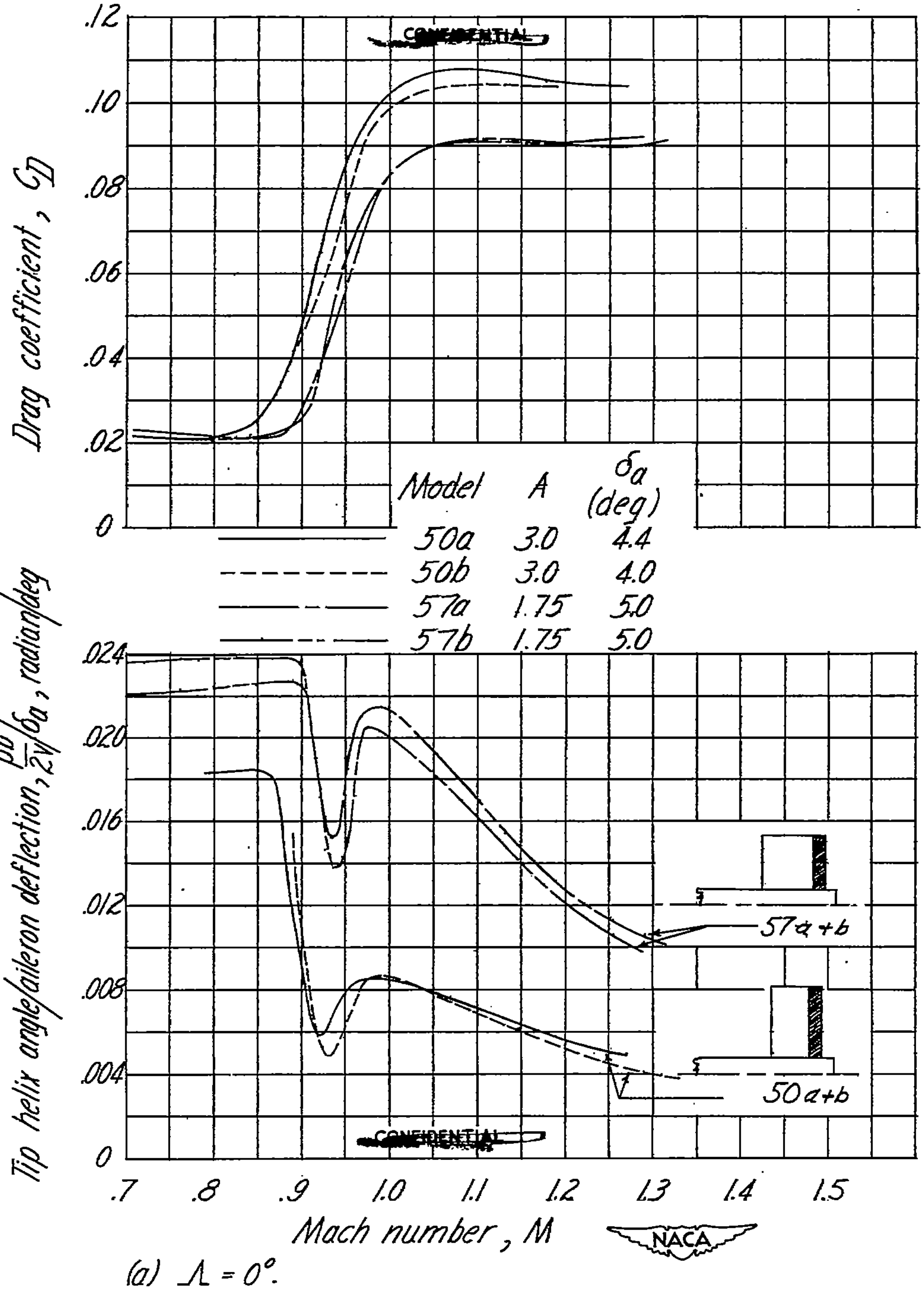
(a) $A = 1.75$.

Figure 8.- Effect of wing sweepback on the variation of $\frac{pb}{2V}/\delta_a$ and C_D with Mach number. Airfoil section, NACA 65-009 ; $\lambda = 1.0$.



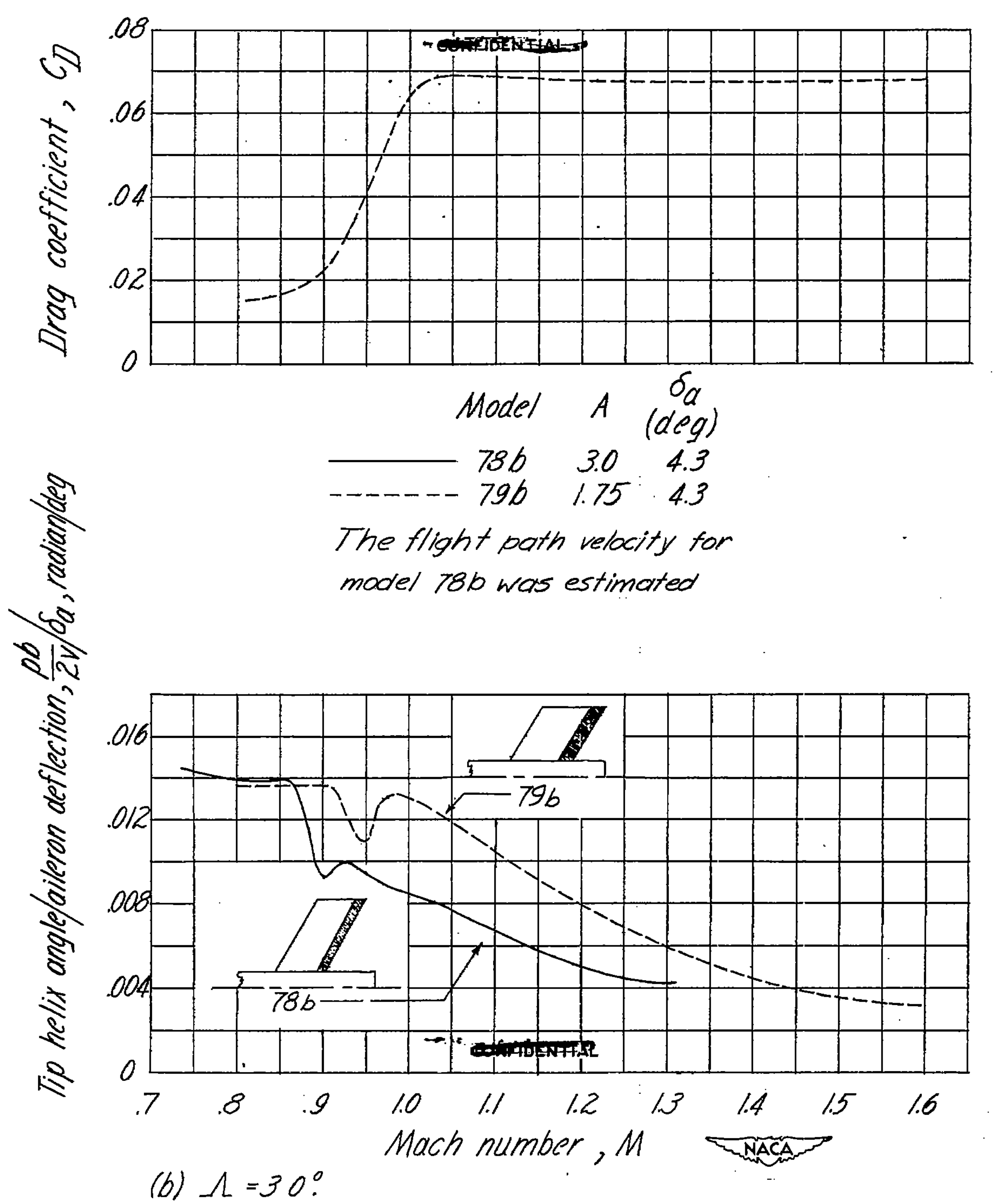
(b) A = 3.0.

Figure 8.-Concluded.

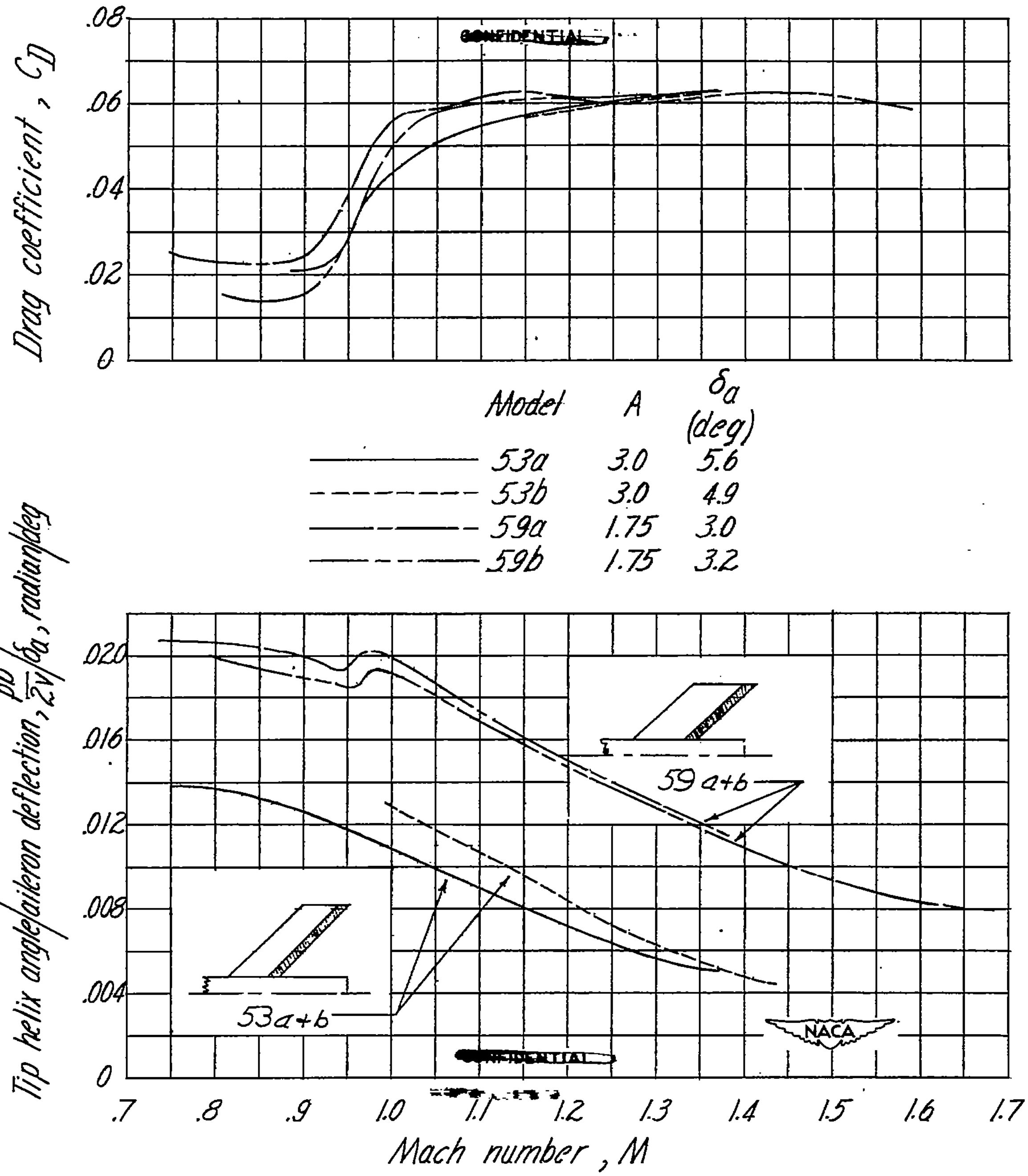


(a) $\Lambda = 0°$.

Figure 9.- Effect of aspect ratio on the variation of $\frac{pb}{2V}/\delta_a$ and C_D with Mach number. Airfoil section, NACA 65-009 ; $\lambda = 1.0$.

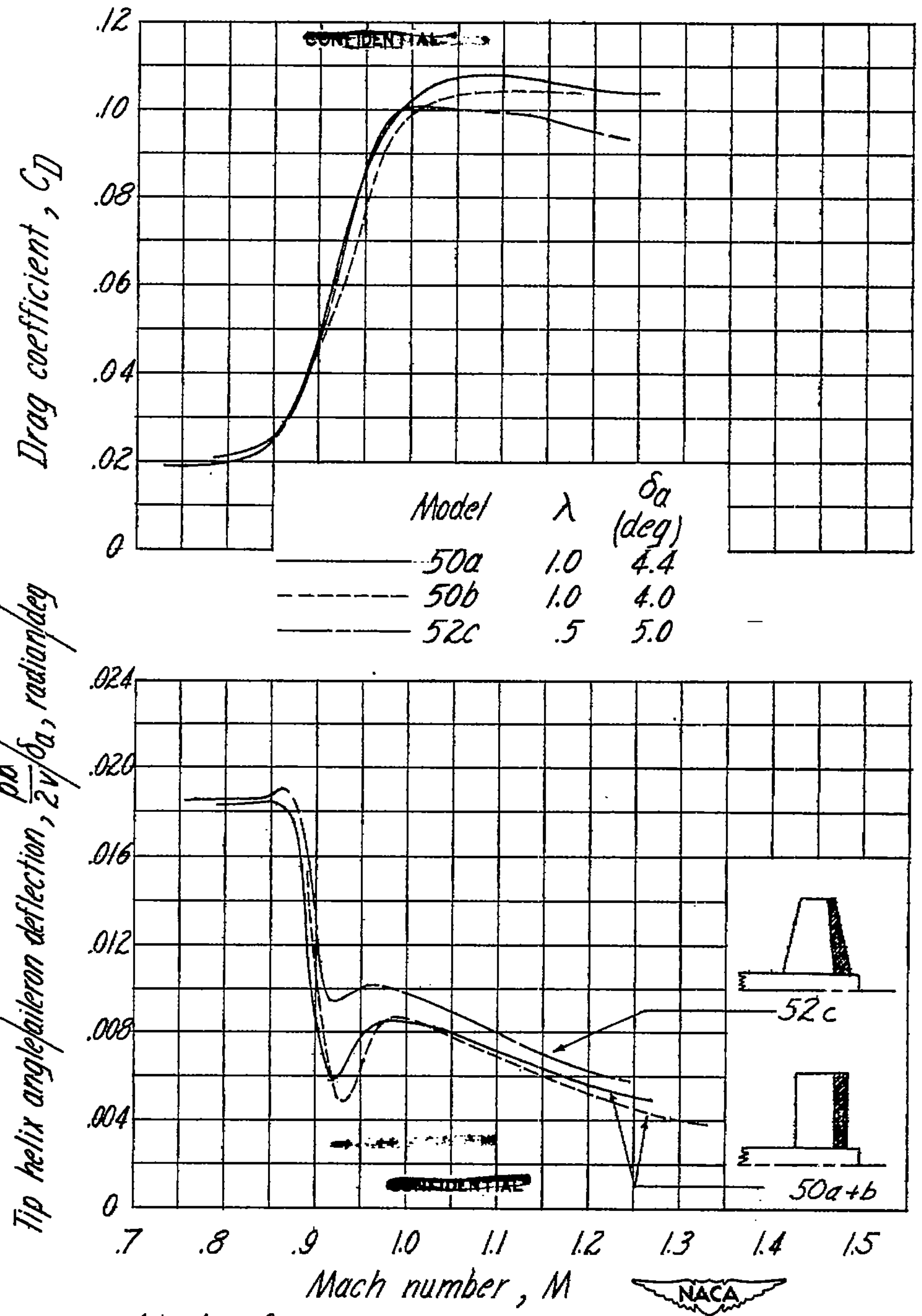


(b) $\Lambda = 30°$.
Figure 9.-Continued.



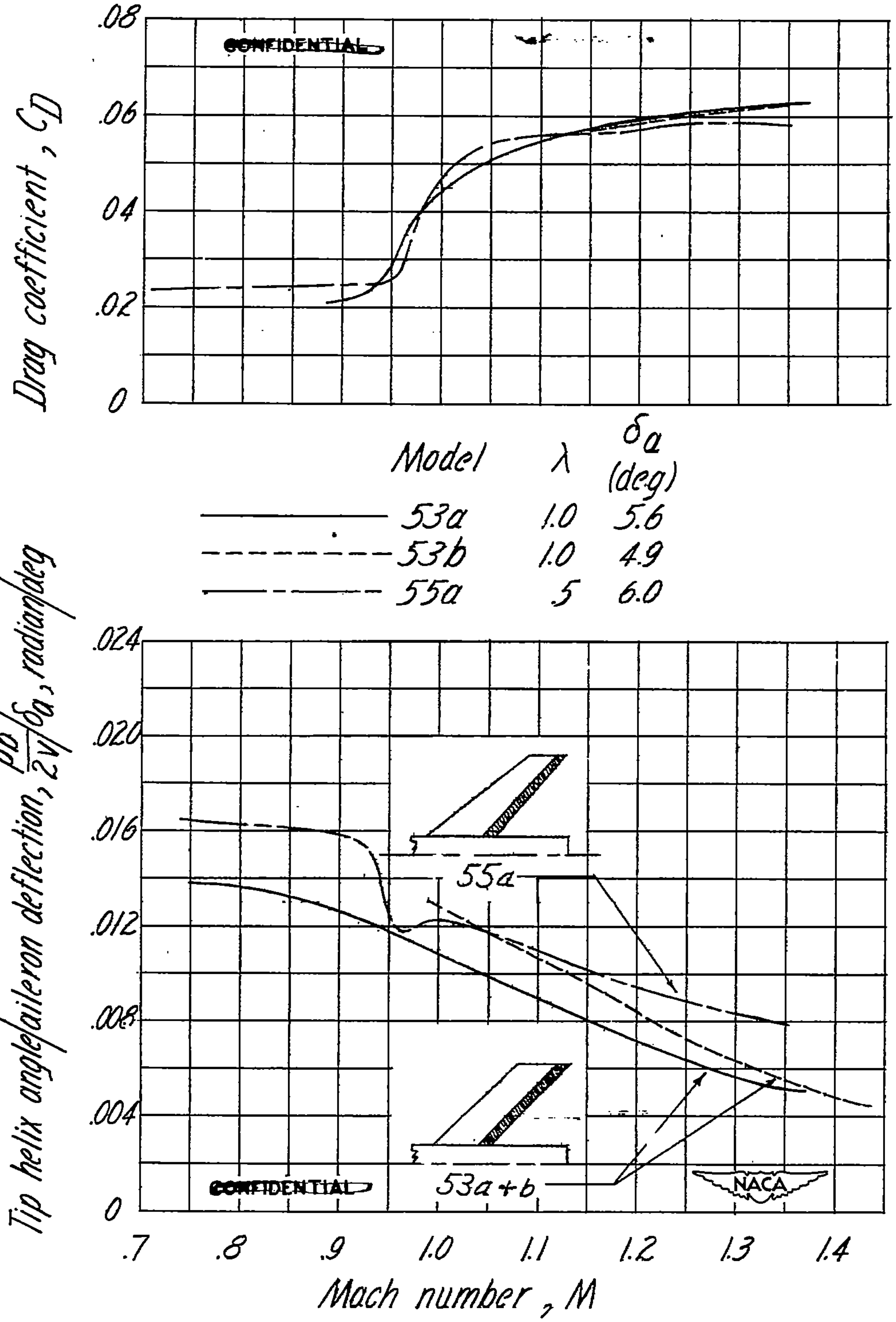
(c) $\Lambda = 45^{\circ}$.

Figure 9.-Concluded.



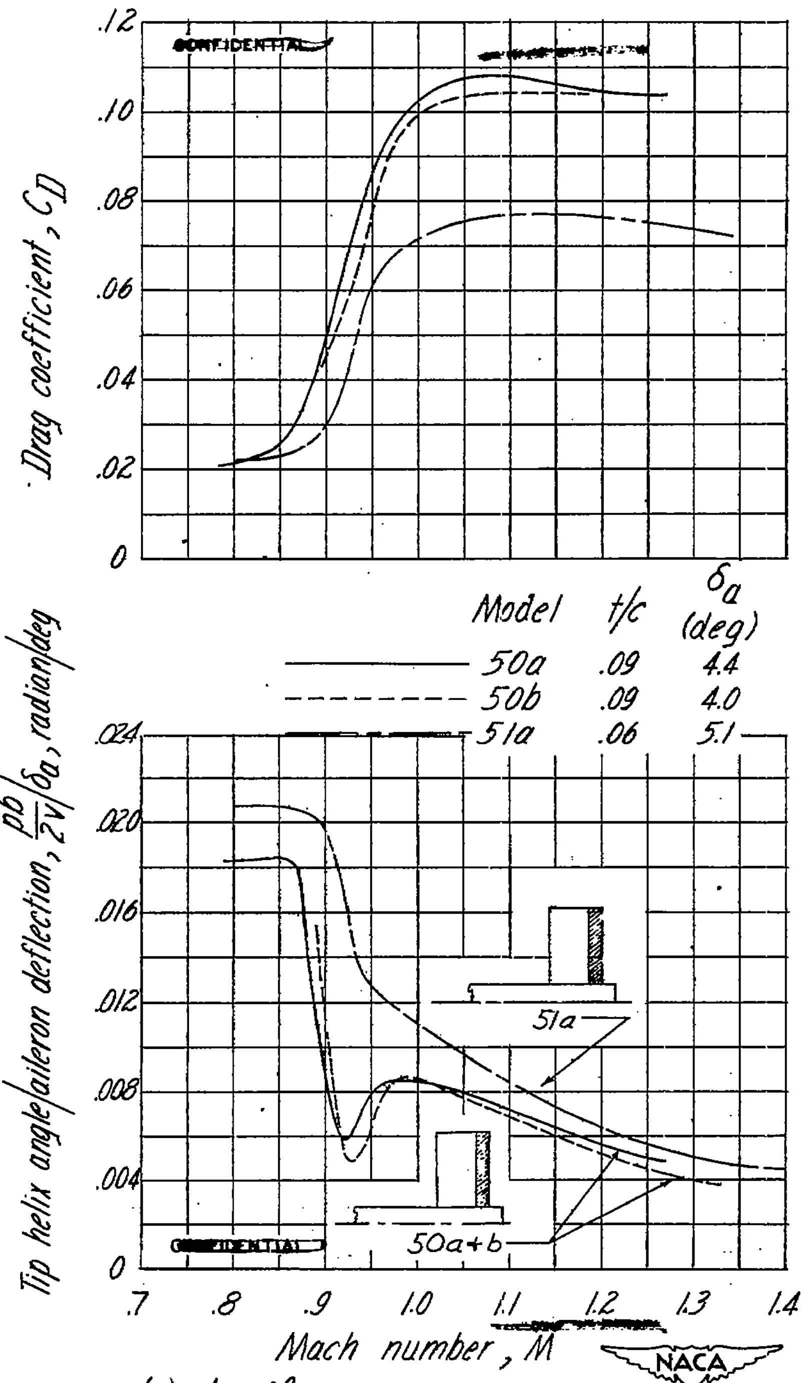
(a) $\Lambda = 0°$.

Figure 10.- Effect of wing taper on the variation of $\frac{pb}{2V}/\delta_a$ and C_D with Mach number. Airfoil section, NACA 65-009; A = 3.0.



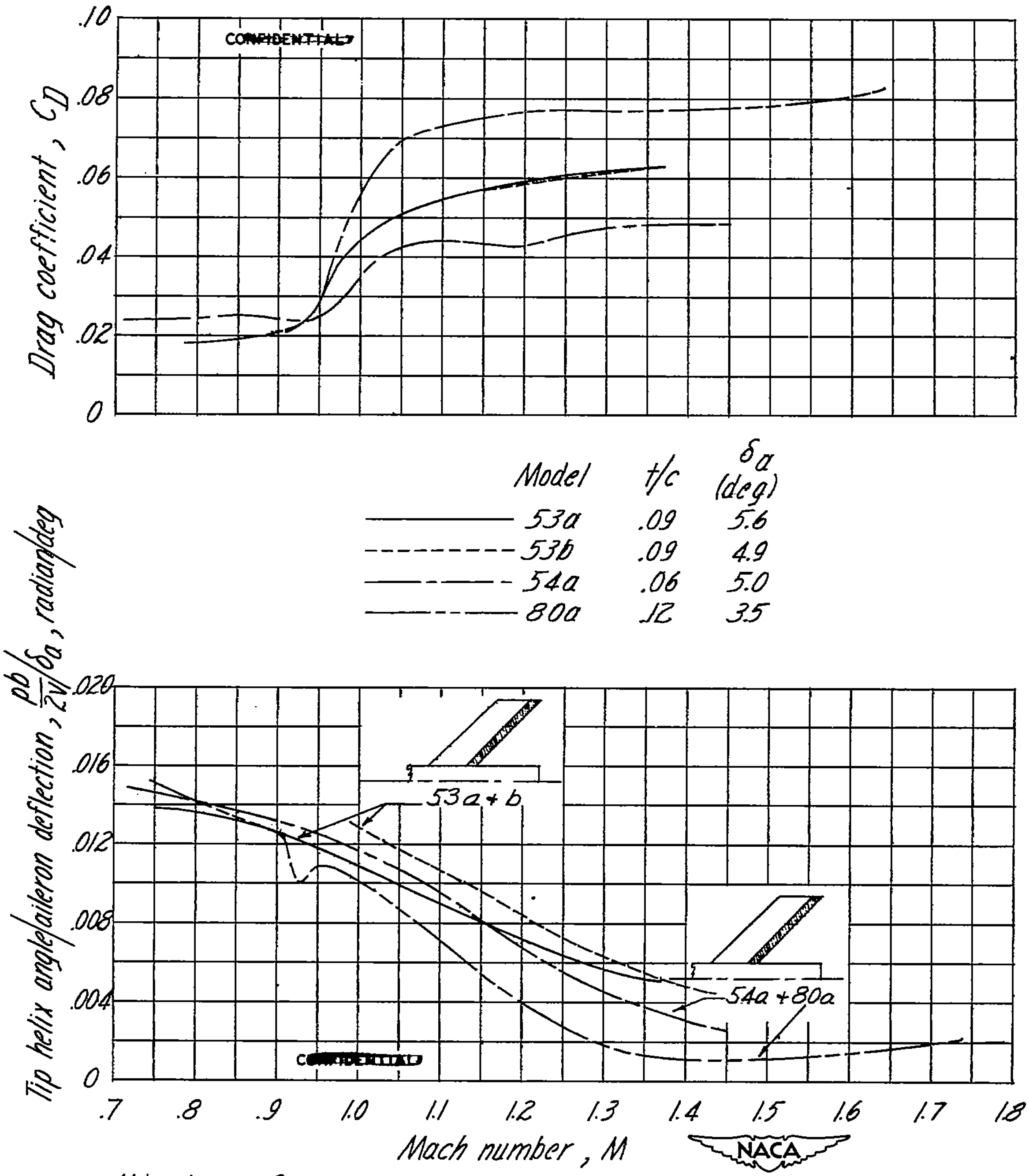
(b) $\Lambda = 45^{\circ}$.

Figure 10.-Concluded.



(a) $\Lambda = 0°$.

Figure 11.-Effect of airfoil section thickness ratio on the variation of $\frac{pb}{2V}/\delta_a$ and C_D with Mach number. $A = 3.0$; $\lambda = 1.0$.



(b) $\Lambda = 45°$.

Figure 11.- Concluded.